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PROFESSOR MACH AND HIS WORK.

AMONG modern physicists Prof. Ernst Mach of Vienna holds a prominent place in the esteem of naturalists and the general public. His success appears to be mainly due to the simplicity and accuracy with which he presents his thoughts, and more than any other scientist he has insisted upon the principle of distinguishing between facts and theories. While he would allow theories to pass as hypotheses, which means as assumptions that help us to think facts in an economical way, he would insist that the facts of existence are the only realities. But the difficulties which beset such a positivism as he represents consist in the question, "What are facts?" Professor Mach, in unison with the majority of philosophers and scientists, accepts our sensations, so far as I can see, as the data from which our investigations start. He analyses these sensations and calls them the elements of the world.

These elements of the world are to him the ultimate facts of reality; and right here Professor Mach finds himself in contrast with other physicists, among whom we will mention Prof. M. Planck who pursues the opposite way and in his "Analysis of the Data of Experience," adopting the current physical and chemical interpretation of matter as consisting of atoms, looks upon these atoms as the ultimate indivisible items of existence and considers them the only real things.

We will here characterize the leading ideas of Professor Mach and at the same time acquaint the reader with the development of his personality, which shall be done so far as possible in his own words.

We will say at once that Professor Mach's significance in science as well as in his private life is based on the straightforwardness of his way of thinking and living. There is no pretense about him. He does not want to appear in a wrong light. He does not decorate himself with the plumes of others and if he exaggerates or goes too far in any way it is only when describing his own shortcomings. His statements in his scientific expositions are always plain and this plainness shows in his private life as a modesty which is the distinctive mark of a truly great man. It is extremely characteristic of him that the notes which he kindly furnished to assist us in understanding his development are almost exclusively a description of his shortcomings in school, and the disappointments which his teachers showed while giving him his elementary instruction.

We must here bear in mind that most original thinkers have been poor scholars. At school we are expected to memorize, and scholars are passed or reprimanded according to the faithfulness with which they are able to repeat, if possible literally, what they have been taught. Thus it is quite natural that those who attempt to think for themselves will not be regarded as shining lights in school, and yet when the demands of life approach us the question is not how well we can repeat what others have said, but how accurately we can think and with what energy we can attend to our duties. From his childhood Mach was not intended to excel by memorizing, but even while his teachers reprimanded him for his dullness of mind, he was thinking for himself, and when he became acquainted with the actual problems of science he was able, as was none of his predecessors, to understand the development of scientific thought and render the methods of scientific progress intelligible. Most of Mach's works, especially his *Science of Mechanics,* are now known as models of clearness and exactness, and the teachers of his early childhood would probably be surprised to learn what a genius was hidden in this slow and dull boy to whom they had given instruction in the elements of human knowledge.

The first important work upon which Mach's fame rests, is his *History and Root of the Principle of the Conservation of Energy*, published in 1872, a considerable time before naturalists had agreed upon the foundation and explanation of the theory of the conservation of matter and energy. The term "energy" was not yet fully accepted in those days, and the title of Mach's book uses in its place the German word *Arbeit,* i. e., "work." His greatest book, *The Science of Mechanics,* appeared in 1883, and we need scarcely fear contradiction if we say that it will remain forever the classical exposition of this important subject. In 1886 Mach wrote a short work, which however is extremely interesting and throws much light on his peculiar way of thinking, under the title *Analysis of Sensations,* and this was followed in 1896 by another compendious work entitled, *The Principles of the Theory of Heat.*

Having more and more concentrated his attention on the problem of cognition he finally published his ideas in their most mature form in 1905, under the title *Cognition and Error.* In the meantime Professor Mach had written a series of articles for various periodicals, among them *The Monist* and *The Open Court,* and the Open Court Publishing Company published a collection of them under the title *Popular Scientific Lectures.* This work was soon afterwards republished in its original German form as *Populärwissenschaftliche Vorlesungen.*

We here publish a review of Professor Mach's life based on notes which he himself furnished and one cannot help admiring the frankness of this great and famous scientist, as he describes the difficulties which he encountered in passing through school.

* * *

Ernst Mach was born February 18, 1838, at Turas in Moravia, and was the son of Johann Mach, at that time tutor in the family of Baron Breton, and his wife Josephine, née Lanhaus. In 1840 his father came into possession of a rather large farm in Unter-Siebenbrunn in the Marchfeld. To this circumstance Ernst Mach owes the fact that he was able to grow up in the country and to enjoy a happy childhood. His earliest instruction was received from his father, and in the year 1847-48 he entered the lowest class in the school of the Benedictines at Seitenstetten in Lower Austria. The good fathers found the boy very lacking in ability but allowed him to pass, advising his father, however, to have him learn some trade or business; and they were right. Neither sentences like *Initium sapientiae est timor domini,* nor declensions and conjugations had any inspiration for Mach, and he would never have become a good memorizer. The only stimulating recitation hour which he remembers was the lesson in geography. No one knew, however, that his imagination was constantly engaged with windmills and other machines as well as with experiments in atmospheric pressure which his father had shown him with the most simple apparatus, a flower-pot and tumbler in a tub of water. Had it been known it would only have injured the dreamy young fellow.

Mach's father was greatly disappointed by his son's poor success and kept him at home in order to take him again under his own instruction in the studies of the gymnasium, comprising Latin, Greek, history and the elements of algebra and geometry. Still the pupil showed but little talent and less interest for the languages, and when some grammatical rule would not stick he often heard the impatient exclamation, "Norse brains!" or "Head of a Greenlander!" As soon, however, as the reading of classical literature began, the study of the ancient languages took on a more friendly aspect, and the student attained considerable fluency in translation and a ready understanding of the texts. It was an advantage too that in these home studies he could read a great deal more than is commonly studied in public schools. In mathematics and physics Mach could soon be left to himself because of the great interest he took in these branches.

Since the morning hours sufficed for study Mach was able to devote the afternoons to various kinds of work in the fields, and from this experience he gained a lasting respect for that part of mankind who live by manual labor.

We must not neglect to mention that the time of Mach's youth bore a strong reactionary and clerical complexion after the overthrow of the revolution in 1848. For this reason the boy, who had grown up in a liberal family, besought his father to let him learn the trade of cabinet making so that he might eventually emigrate to America. His wish was granted. For more than two years two full days in the week were devoted to this employment under the guidance of a skilled mechanic in a neighboring town. This period too Mach holds in grateful remembrance, and many an experience gained while thus working in wood proved very useful to him in his later vocation. He remembers with pleasure the agreeable feeling with which, when physically wearied in the evening, he would sit on the fragrant woodpile and at his leisure construct pictures of future machines, air-ships and the like. From this experience the thinker learned how much he owed to the laborer.

Mach's father was especially conversant with Latin literature and history and was at the same time an excellent story teller. Although he had never had a profoundly scientific education he could be very stimulating to the children, because of his love for nature which he was fond of observing, and especially because of the anecdotes he could tell about Archimedes and other ancient investigators, after Vitruvius, Plutarch, and others. The flora and especially the splendid fauna of insects did their share to induce the boys to make collections and to take pleasure in the different forms and their comparison. Guests seldom came to Siebenbrunn, but on summer Sunday afternoons almost all the larger children of the village, both boys and girls, would come to gather around Mach's father in the garden and learn the nurture of fruit-trees, grafting etc., which instruction was delightfully sweetened by the enjoyment of the fruit itself. Otherwise the young Mach's intercourse was limited to his father, mother, and two younger sisters, so that there could be no question of social pampering nor did he acquire the art of being bored.

At the age of fifteen, after passing the entrance examination, Mach entered the sixth class of the public Piarist gymnasium in Kremsier, Moravia. He did not get along very well at the start because he lacked the cleverness and cunning prevalent in schools, and these had first to be acquired. In general the teachers were not especially scholarly, but certain ones of them Mach remembers with pleasure, esteem and particular gratitude.

An especially amiable man was F. X. Wessely, the instructor in natural history, who not only was filled with zeal for his specialty, but knew how to communicate this enthusiasm to his pupils as well. He taught them the theory of Lamarck, and also the Kant-Laplace cosmogony, without losing any words over the incompatibility of these teachings with the Bible. Mach remained in connection with him until he died at an advanced age only a few years ago.

The teacher of physics was a remarkable didactician, who knew how to rouse the interest for his subject to the highest pitch, but unfortunately was too impatient to be a good instructor. To the teacher of Greek, F. M., an enthusiast for Greek culture, who saw, or at least wished to show, only its bright side and who was a worshiper of Greek grammar, Mach remained permanently indebted for the forbearance which made this subject endurable to him. Mach who had no interest for dynasties and histories of war and at the same time possessed a very bad memory, did not get along well with his teacher of history. But while his teacher gave tests from the dry chronology of Pütz, he would also read by the hour from large volumes of history and original sources, so that the students did not receive the impression that the spiritual and secular rulers of the world had performed only such duties as were ostensibly assigned to them by God and had had only the welfare of their subjects at heart. In the higher classes the pupils had occasion to learn also of such occurrences as are brought to the knowledge of the public in Max Kemmerich's *Kulturkuriosa* which served to throw light on the whole course of history.

Although as a whole the system was reactionary-clerical, yet there were men enough there in whom the traces of the liberal influence of Emperor Joseph II had not passed by without leaving an effect, and who interpreted in this spirit their calling as teachers. The only unpleasant details were the rituals, the everlasting religious exercises, which accomplished a result exactly opposite to that desired. When Mach protested to his father with regard to these things and complained about them, he only received the answer, "If you had grown up under the Chutchkas or the Samojeds you would have to stand things much worse." Perhaps such an education even accomplishes some good. Sometime later in his life (1898) when on a journey through Tyrol, Mach overheard one of his traveling companions, an elderly officer, give the following answer to a question about the particular architecture of some church: "I'm sure I don't know; I don't go to church any more. I had enough of compulsory mass and religious exercises in the Gymnasium." On the whole Mach's attainments in this school must be looked upon as but very ordinary,—probably chiefly because he did not receive the call to his life's vocation here, for that had already been determined before he entered this school.

Mach was finally graduated from the Kremsier gymnasium, and he could not help considering it an especial piece of luck because of his bad memory and the custom at that time to make the tests include every conceivable detail. His good fortune was illustrated by the fact that at the same time the boy who was first or second in the class was prevented by the chairman of the commission, the so-called school councilor, from passing, probably because that gentleman suffered from an attack of Cæsaromania. The poor fellow, to be sure, was not a shining light but so industrious and conscientious that he would certainly have filled a place creditably in any walk of life. Those who failed to graduate were at that time admitted to the study of theology, and while pursuing this course Mach's unfortunate schoolmate died.

At the age of seventeen Mach matriculated at the University of Vienna in order to devote himself to the study of mathematics and physics. Count Leo Thun, the minister of instruction, had, to be sure, introduced many reforms into the university by appointing to its faculty many scholars of a high grade, and yet the departments of mathematics and physics were hardly touched by this change. At first indeed the new era of liberalism in instruction seemed only to have the result of entirely neglecting the needs of beginners. Students were obliged to gain the indispensable knowledge of differential and integral calculus by themselves in order to be able to understand the lectures offered in the courses of the university.

Of these lectures the addresses of Von Ettingshausen on mathematical physics certainly did not deserve the insolent and highhanded judgment with which they were branded in a lecture by Liebig, who was not even well posted in this department. It is true that Ettingshausen was not a creative genius in his line to any important extent, but such investigators were rare enough even in Germany at that time, the French being then still in the lead in scientific work. Petzval was a highly talented teacher of mathematics, somewhat indolent and rather unapproachable; he is known for the reforms he has worked in photographic optics. Stimulating too were the lectures of young Professor Grailich whose career at the university, however, was early terminated by his death. Ettingshausen was also director of the Physical Institute, the first institution of its kind, at least at that time, in Austria and Germany.

While at the university, Mach succeeded in bringing to completion his first modest work which was an apparatus that he had himself designed and for the most part constructed and which was followed by several other similar tasks. In January, 1860, Mach took the degree of Doctor of Philosophy according to the somewhat medieval custom of the time which required the applicant to pass three tests in several subjects of two hours each, insisting upon a mere diversified smattering which was at the same time compatible with great ignorance. Because of his slender means Mach was now compelled to renounce his ardent wish to take advantage of the instruction of F. Neumann in Königsberg, and instead he was obliged to consider how to gain his own livelihood by giving private lessons.

However, under these discouraging circumstances he was bold enough to qualify as a private docent in physics without knowing how he was to live the following year.

Indeed at this juncture it was indispensable for him to earn money by private lectures on mathematics, Fechner's psychophysics and Helmholtz's tone sensations as well as by ordinary tutoring, in order to make both ends meet. Naturally in this way valuable time was lost which might have been spent on study for himself and in his own particular work. Still Mach's lectures soon attracted a number of select hearers who afterwards became famous. By his intercourse with the two important physiologists of Vienna, E. Brücke and C. Ludwig, Mach gained an insight into the scientific life of Germany and came also upon a line of work which he could follow with some success without any particular scientific equipment. This was the domain of the physiology of the senses which gradually led him to his critical researches in the theory of cognition.

By a happy accident Mach was appointed in 1864 to fill the vacancy in the chair of mathematics in the then somewhat neglected University of Gratz at a salary of ten hundred and fifty gulden. This appointment came just as his strength was about to fail him, but he now soon recovered when thus relieved from actual want and privation. Three years later he became professor of physics at the University of Prague, which offered him also the opportunity to invest in more extensive equipment for experimental work. His remuneration of 1300 gulden gave him courage to marry Luise Marussig, with whom he had become acquainted as an orphan in Gratz. Now he lived in the most modest manner, obtained a circle of zealous pupils and from 1868 to 1881 saw his family of four sons and one daughter grow up about him. In the meantime he had lost his mother in 1868 and his father in 1880, who had bought property in Carniola, and as a consequence of a series of especially bad harvests had remained burdened with cares to the end of his life.

Mach too endured a period of great anxiety when in

1880 the attendance at the German university at Prague fell off greatly because of the establishment of the Bohemian university there, and his own income was correspondingly diminished. Then he endeavored to repair the loss by special technical work. In fact in a few weeks he earned about as much as a year's salary but realized at the same time that this manner of living could not be combined with scientific work. The money he had made, however, made it possible for him to attend a congress of electricians at Paris in 1881 which was of so great an advantage to him by the increased inspiration it gave him, the new personal acquaintances he formed and the additional employment obtained through them, that his financial situation was greatly improved in the following years.

By this time Mach had obtained sufficient leisure to prepare for publication his critical studies in the theory of cognition. In 1883 he published his *Mechanics*[1] and soon afterwards his *Analysis of the Sensations.*[2] Perhaps he placed too high a value upon the importance of these works, for he was so unwilling to be turned aside from them that in order to remain in his present position he determined to reject an advantageous call to Munich. Since his studies in the theory of cognition were now greatly interrupted by many experiments, even though the number of young people taking part in the latter was constantly increasing, Mach accepted an invitation of the University of Vienna in 1895 to take the chair of philosophy which made it possible for him to give his exclusive attention to his critique of cognition. Shortly before this he suffered the loss of a talented son who ended his life by suicide after a fine promotion in Göttingen.

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[1] The full title was *Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt.* English translation by T. J. McCormack, *The Science of Mechanics: A Critical and Historical Account of Its Development,* Chicago, Open Court Pub. Co., 3d ed. 1907.

[2] *Beiträge zur Analyse der Empfindungen.* Engl. ed., *Contributions to the Analysis of the Sensations,* transl. by C. M. Williams. Chicago, Open Court Publishing Co., 1897.

Mach's *Principles of the Theory of Heat*[3] which deals essentially with the critique of cognition was published in 1896. During the preparation of a corresponding work upon optics (1898) Mach suffered a stroke of apoplexy which crippled him permanently without however destroying consciousness or memory. His capacity for work was so diminished for a few years that he could accomplish nothing except new editions of earlier writings. A portion of the lectures held by Mach at Vienna in 1895 were not published until 1905 when they appeared under the title *Cognition and Error.*[4]

* * *

The principles which Professor Mach followed in explaining the progress of science have been laid down in a recent article of his which appeared under the title "My Leading Thoughts."[5] Remembering what Professor Mach said of his life when he worked on a farm and passed through a period of apprenticeship as a cabinet maker, we can well understand that he saw in science only a product of the division of labor. Science appeared in the course of human evolution because it was needed for economical reasons, and the methods of science themselves must be economical. Thus Mach arrived at the conclusion that the method of science consists in an economy of thought. Science is a survival of the fittest, and those scientific theories survive which are best adapted to facts; our thoughts are an adaptation of thinking to facts and also of thought to thought. Professor Mach says:

"When in the beginning of my educational work as private docent of physics in 1861 I began to pay attention to the labors of investigators to whom I had occasion to refer, I recognized that the salient characteristic of their procedure lay in the choice of the simplest, most economical, most direct means to attain the end desired. Through my intercourse in 1864 with the political economist E. Hermann, who, according to his specialty, sought to trace out the economical element in every kind of occupation, I became accustomed to designate the intellectual activity of the investigator as economical. This becomes apparent in the simplest instances. Every abstract comprehensive expression of the behavior of facts, every substitution of a numerical table by a formula or rule of construction, the law by which it was compiled, every explanation of a new fact by one that is better known, may be regarded as rendering an economical service. The farther we analyze in detail scientific method—its systematic, organizing, simplifying and logico-mathematical arrangements—the more we recognize scientific procedure as economical."

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[3] *Die Principien der Wärmelehre.* English translation in preparation.

[4] *Erkenntnis und Irrtum.*

[5] *Die Leitgedanken meiner naturwissenschaftlichen Erkenntnislehre und ihre Aufnahme durch die Zeitgenossen.* Published in *Scientia,* Vol. VII (1910) No. XIV, 2.

Starting from the economical standpoint, Mach was well prepared to understand the progress of science, which is an advance from complicated explanations to more and more simple ones, as for instance Kepler's laws were replaced by a single formula of Newton, which expresses them all in the equation

$$\frac{d^2r}{dt^2}=\frac{mm^1}{r^2}$$

As economists teach that the wealth of nations is increased by economy, so Professor Mach sees the cause of scientific progress in an economy of thought, an idea which was foreshadowed by Adam Smith. Mach has worked out and exemplified this idea in many of its details and made it a cornerstone of his conception of science.

He felt isolated in his mode of thinking for a long time, but gradually he found straws in the wind which indicated that similar views began to prevail in other quarters. As such he mentions the conception of Avenarius's "Philosophy as a Mode of Thinking the World According to the Principle of the Least Effort" (1876); also Petzoldt's "Introduction to the Philosophy of Pure Experience" (1900); Schuppe's "Logic of the Theory of Cognition" (1878); and W. J. M. Rankine's "Outlines of the Science of Energetics" (1855), which latter work is also a predecessor of Ostwald's "Energetics." Professor Hertz once said that Maxwell's theory consisted practically of Maxwell's equations; and finally P. Duhem in his "Physical Theory" quietly surrendered the old metaphysical standpoint.

Professor Mach's lifework is that of a scientist who has paid special attention to scientific method. He is not a philosopher, as he himself has frequently stated. He is a scientist who feels the need of comparing his science with other sciences and becomes conscious of the nature of the method in his work. If such is philosophy he ought to be called a philosopher and we would be the last to begrudge him the name; nevertheless we would not classify him as a typical philosopher, for he halts at the place where a philosopher ought to begin work. He discovers the principle of an economy of thought and the mode of action which science instinctively pursues wherever scientists work. Nowhere in his writings has he attempted to investigate the nature of this principle, which he would have done if he were a philosopher in the common acceptance of the word.

In further explanation of Mach's theory we would say that a philosophical explanation of his principle of economy can be given and is to be found in the nature of the purely formal sciences. We have set forth our explanation of the significance of the purely formal sciences in other articles and do not propose to repeat ourselves. We will only say that the dissatisfaction which Professor Planck experiences in reading Professor Mach's works is caused perhaps to a great extent by Professor Mach's unwillingness to enter into any investigation of the nature of generalities of any kind, be they theories, generalizations or the conception of units. The fact is that this is not a shortcoming of Mach's as much as an unwillingness to work in a definite field where he feels uneasy. As soon as Professor Mach loses the solid ground of concrete facts he feels the thin air of abstraction, and he has a deep seated prejudice against anything that is not tangible or sensible. Generally speaking, theories become inaccessible to sense perception. Thus the scientific concept of a kinetic physical world such as is constructed in the theory of atoms, is to him a respectable hypothesis, nothing more; and he refuses to accept Professor Planck's idea that these atoms are the only true realities.

We will not enter at present into an exposition of these two contrasts, but will only say that Professor Planck did not understand Mach and rather hastily called him "a false prophet," in response to which Professor Mach has most emphatically protested against dogmatism in science, saying: "We can see that the physicists are on the surest road to becoming a church, and are already appropriating all the customary means to this end. To this I simply answer: 'If belief in the reality of atoms is so essential for you I hereby abandon the physicists' manner of thought (Planck, p. 31), I will be no regular physicist (*ibid.*, p. 33), I will renounce all scientific recognition (*ibid.*, p. 35); in short the communion of the faithful I will decline with best thanks. For dearer to me is freedom of thought.' "

A few quotations will characterize Professor Mach's view in his own words. He says:

"We have colors, sounds, pressures, and so forth (A

BC...), which as simplest component parts, make up the world. In addition thereto, percepts (resolvable into $\alpha\beta\gamma$...), feelings, and so forth, more or less composite. How $\alpha\beta\gamma$... differ from A B C... I will not define here, for I do not know exactly. It is enough for the time being that they do differ from A B C..., as the latter do from one another. And let us now leave $\alpha\beta\gamma$... entirely out of account and put ourselves in a time and state in which there are only A B C. Now I say, that if I see a tree with green leaves (A), with a hard (B), gray (C) trunk, that A B C are *elements* of the world. I say *elements*—and not sensations, also not notions—because it is not my purpose at this place to arrive at either a psychological or a physiological or a physical *theory,* but to proceed *descriptively.*" (*Monist,* I, 394).

"For us, therefore, the world does not consist of mysterious entities, which by their interaction with another equally mysterious entity, the ego, produce sensations, which alone are accessible. For us, colors, sounds, spaces, times, ... are the ultimate elements, whose given connection it is our business to investigate...

"Science always takes its origin in the adaptation of thought to some definite field of experience. The results of the adaptation are thought-elements, which are able to represent the field. The outcome, of course, is different, according to the character and extent of the province surveyed. If the province of experience in question is enlarged, or if several provinces heretofore disconnected are united, the traditional, familiar thought-elements no longer suffice for the extended province. In the struggle of acquired habit with the effort after adaptation, *problems* arise, which disappear when the adaptation is perfected, to make room for others which have arisen in the interim...

"If we regard *sensations,* in the sense above defined, as the *elements of the world,* the problems referred to are practically disposed of, and the *first* and most important adaptation effected" (*Anal. of the Sensations,* 23-25).

Professor Mach's principle which we heartily endorse is "to proceed descriptively," and we must distinguish between facts and theories. The question is only, What are facts?

Professor Mach insists that the only realities are the elements of the world. Even the unity with which these sensations fuse into things is suspected by Mach. He has acquainted himself with Kant's idea of the thing-in-itself and has come to the conclusion that there is no sense in accepting a thing-in-itself, but in the thing-in-itself he rejects the reality of these unities of the elements of sensation which we call things. To think of a non-sensual bond of the elements in the form of a substratum of their quality and in the form of a substance of the body in the old philosophical sense is excluded, and so he speaks of this idea as being due purely to poetic imagination.

Here Mach goes too far. While we ourselves would reject most emphatically the assumption of things-in-themselves, we are not prepared to deny the reality of things; or in other words we would recognize that a group of elements of existence (and it is here indifferent whether we say of reality or of sensation) are compounded into unities which constitute the thing. These unities are not mere fictions, they are realities, for the very way in which unities combine actually makes new things. A watch becomes a watch when the works are so constructed that its wheels move and its hands point out the time. The bond which interconnects the parts of the watch is not indifferent but the mode of the composition of the parts is essential, and either does or does not produce a new unity which we call a thing. Aside from the reality of its parts their interaction constitutes what we call a watch. If a certain number of elements into which Mach analyses his sensation are combined in what we call the sensation of a thing, an actual unity is produced which we will call the object of perception, and this unity is not due, as Mach seems to say, to our own poetic imagination, but we are confronted with a unity which is the result of a definite cooperation, and there is a good reason for assuming that the unities of perception are founded in the nature of things. The combined parts of a tree constitute an organism which is more than merely the sum total of all its elements. The same is true of other non-sensual unities, as well as of generalities.

It seems to us that the primitive realities are the things with which we become acquainted. They are the given facts, and we call them the data of experience. What Mach calls the elements of existence are not so primitive as he seems to assume. His elements are really the result of an analysis; they are of an artificial nature and can exist only in the mind of a highly trained scientist like Professor Mach. If they were truly elements in the sense of ultimate realities, or what we call data of experience, they would be more obvious to the unsophisticated observer, to the child, to the peasant, to the unschooled, but we would look in vain for any clear conception of these elements. The naive observer of life knows only of whole things and of their several activities, not of their ingredients or elements. And the reason is obvious when we understand that the unities of things are as such actualities, and these actualities affect man's senses and become the objects of his observation.

We must assume that the sense impressions of a baby are not distinct elements such as hardness, whiteness or greenness, sweet or sour tastes, definite notes or distinct sounds, etc., but a chaotic mass of feelings, a kaleidoscopic blur from which certain groups gradually and clearly rise. Things and persons are such groups. They consist of elements of sensation, but the groups themselves are heeded and not their several elements. These groups are constants, i. e., combinations which are stable, and the unity of a group of sensations is conditioned by the unity of things themselves.

These unities are made by nature, they are founded upon the existence of unities in the objective conditions of the world; they are not purely mind-made nor are they artificial. The mental image of a cat exists prior to the distinct notions of the several sensory elements of which a cat-perception is composed, and we have no doubt that what an animal sees is a thing, but not the sense elements into which the physiological psychologist can analyze it.

Mach is a representative of the old nominalistic school. According to its principles things are mere names, and the further application of this appears in their conception of the nonexistence of generalizations. Nominalists treat abstract ideas as inventions of a purely subjective nature.

The generalizations of what we call natural laws are not mere fictions, but they represent general features in the world of reality which though they are in no definite place can be traced wherever the conditions are fulfilled. The laws of nature in their perfected shape are not mere theories, but uniformities, and by uniformities we understand descriptions of fact—not of concrete facts in a compact existence, but generalized formulas of the essential features of certain phenomena, which summarize the essentials that determine certain results.

Accordingly the picture of the world which science aims at is not a mere illusion but aspires to the actualization of a predetermined ideal, which would be a description of the characteristic features of the constitution of the world.

What Professor Mach calls "elements of the world" we call "data of experience," and whatever we are compelled to grant existence independently from our thought we call fact. The data of experience are facts, but in addition there are other facts with which we become acquainted by inference and we see no fault in assuming them to be as real as the data of experience.

Our point of view is different from Mach's, but, like himself, we see no harm in approaching a problem from different standpoints, yet we wish that Mach had in his own way gone one step further in the work of explaining the nature of science, by pointing out why an economy of thought is possible. This would have led him to the conclusion which we have offered in what may be called the philosophy of form. The formal sciences are different from the sciences of experience in this important point, that they are systematic, and the systematic nature of the formal sciences makes it possible to systematize thought. The sameness of form as form under different conditions makes it possible to think of different things of the same shape as types, and thus logic can classify things always according to their forms as genera and species. If experience could not be treated by the formal sciences, they would present a chaos of detailed items which would never allow us to reduce them to order. It is obvious therefore that the formal sciences alone offer us the methods through which an economy of thought is possible.

We do not wish to exaggerate the difference between Professor Mach's views and our own. We will therefore state that Professor Mach also insists on the significance of form, but he speaks of it as the functional dependence of the sense elements upon one another (*funktionelle Abhängigkeit der sinnlichen Elemente von einander*). However, we believe that our thoughts are on converging lines. We have no right to criticize Professor Mach for not having followed out a problem which he had not proposed to himself, and at the same time, we feel the injustice of those of his critics who would demand of him that he should use the same expressions as are commonly in use among physicists.

Professor Mach is right that physics is only one mode of picturing the world, and the physical world-picture does not exhaust the nature of being. There are other points of view which can be taken. The psychical facts are not less true and the bio-economical mode of viewing the world is certainly as much justified as the physical theory.

It is the duty of philosophy to bear all this in mind. The scientific conception is of crucial importance, but the religious, the poetic, the artistic, the emotional aspects have rights of their own and it would be an indication of narrow-mindedness not to allow them their right of existence. If they in their turn raise the claim of exclusiveness and if the church attempts to curb science or free scientific inquiry, we complain about intolerance; should science now walk in the footsteps of the old dogmatism?

We can live in peace with every point of view if we proceed descriptively, and while we state facts we need not be inhospitable to theory. It may sometimes be difficult to draw the line between facts and theory, but it is possible, and problems of this nature can be settled.

The truth is that science as well as religion passes through a period of myth formation which is quite natural in so far as man fills out the gaps of his knowledge in the most plausible way, according to the then obtaining conditions of the state of his mind. The fictions which we thus introduce into science by analogy, or as helps to think the unknown in terms of the known, may be wrong or, as is mostly the case, only partly right, but they serve a good purpose as approximations to the truth. Beyond them looms the ideal of all science which is a generalization of descriptions of fact—or of features of factual reality in the shape of accurate formulas.

We are not blind followers of Professor Mach, but we see that he has promoted the scientific comprehension of the nature of scientific method as few others have done in the history of science. For generations to come his works will remain classical instances of the genuine spirit of science, exemplifying the attempt at an accurate description of facts—in the search for truth.

There is one peculiarity about Professor Mach's writings. He appeals most powerfully to a certain type of thinkers who distrust theory and wish to remain in contact with facts. Among these readers are not only naturalists and inventors, but also people who have not passed through the mill of academic or scientific training. Of the former class I recall the high esteem with which Nicola Tesla spoke of Mach, and of the latter I will mention a remarkable Scotch workman, John Glen of Glasgow, with whom I have been in correspondence. Mr. Glen is typical of that class of men who naturally find in Mach a source of inspiration, and though he is unusual in his attainments, acquired by his own efforts while living on the returns of manual labor, I am sure that there are many more real thinkers scattered among the working classes of all countries.

Mr. Glen takes an interest in the problems of life, the soul and kindred subjects. He has familiarized himself with standard books and expresses his views thus:

"The history of metaphysical psychologies or philosophies is merely one long sorrowful sequence of credulities dogmatically imposed upon the world's unwary, and when I reflect on the public boastfulness of the latter (the mundane gods) and their relative capacities to think, I am impelled to say that they have not yet begun to think of thinking. They can not distinguish between an artful assertion and a demonstration. In short, these types of men are the sports of a derelict brain afloat on an ocean of memories dangling in imagination."

It speaks well for Mach that a man of this type, a self-trained thinker of independent judgment, who does not accept traditional theories on authority, finds himself indebted to Mach's works, his *Aanalysis of the Sensations,* and especially to the *Science of Mechanics,* and agrees with the view of a friend who speaks of Mach as "a philosophical landmark."

There is an individualistic tendency now current in the world of science and philosophy; it is a reaction to both the absolutism in philosophy which reached its climax in Hegel, and the materialistic dogmatism of science which is most drastically represented in Karl Vogt and Büchner, while it found its best and most dignified exponent in Haeckel. Both contrasts are wrong. They are formulations of an exaggerated objective philosophy and the opposition to it shows itself most potent in the individualistic upheaval of pragmatism with its denial of "truth" in the singular and its advocacy of "truths" in the plural. But pragmatism is only a symptom of a movement that has spread over a wide circle of thinkers in France and Germany who are not directly allied to it. Mach is not, properly speaking, a pragmatist, but he prepared the movement and belongs to it; indeed he is its most important pioneer on account of the sober and truly scientific character of his work. It is true he is not typical of pragmatism itself because he does not go to extremes as did William James. The pathological feature is absent in him, but for that reason he is greater than his successors and by his methods we gain a vantage ground for scientific work. He does not block our path by erroneous theories, and his individualistic tendency is due to the fact that he fights shy of metaphysical theories. Yet even from individualistic principles we can reach a conception of truth in the singular, or, to put it more guardedly, of system in the bewildering details of scientific inquiry.

Mach is an individualist but he keeps within bounds, he does not fly off in a tangent when he hesitates to assume the metaphysical arguments for an objectivism of theories, and so there is naught of pluralism in him, naught of subjectivism, naught of a denial of truth in the singular. We have no right to blame him if he only tentatively and almost timidly outlines the presence of a oneness, not as an objective fact, but as an efficient factor in this world in which economy can accomplish such wonderful results not only in the domain of industry and commerce, but also in science. Mach knows very well that economy is due to systematizing, and systematizing presupposes the possibility of system. Mach has been very instructive to me because he is so cautious. I shall be the last to reproach him for limiting his work to the field which has proved fittest for his talents, his interests and the history of his scientific development. I hope that I have taken the step for the omission of which he has been blamed and decried as a wrong prophet. I would scarcely have been able to accomplish the work he did, and if my work will help to complete his, I shall feel happy and be proud that I could cooperate with a man of his significance.

Let me add that Mach is not only great as a scientist, but also as a man, and I wish that other scientists would imitate his unpretentious habits and the breadth of his mind in not refusing to learn from others and to acknowledge their merits even if they were his inferiors in scholarship and training.

EDITOR.